

DOT/FAA/TC-17/33

Federal Aviation Administration
William J. Hughes Technical Center
Aviation Research Division
Atlantic City International Airport
New Jersey 08405

Recommended Part 147 Curriculum for Composites

November 2017

Final Report

This document is available to the U.S. public through the National Technical Information Services (NTIS), Springfield, Virginia 22161.

This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov.



U.S. Department of Transportation
Federal Aviation Administration

NOTICE

This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof. The U.S. Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the objective of this report. The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the funding agency. This document does not constitute FAA policy. Consult the FAA sponsoring organization listed on the Technical Documentation page as to its use.

This report is available at the Federal Aviation Administration William J. Hughes Technical Center's Full-Text Technical Reports page: actlibrary.tc.faa.gov in Adobe Acrobat portable document format (PDF).

Technical Report Documentation Page

1. Report No. DOT/FAA/TC-17/33		2. Government Accession No.		3. Recipient's Catalog No.	
RECOMMENDED PART 147 CURRICULUM FOR COMPOSITES				5. Report Date November 2017	
				6. Performing Organization Code ANG-E281	
7. Author(s) John S. Tomblin and Allison Bonitati				8. Performing Organization Report No.	
9. Performing Organization Name and Address Wichita State University 1845 Fairmount Wichita, KS 67260-0093				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No.	
12. Sponsoring Agency Name and Address U.S. Department of Transportation FAA National Headquarters 950 L'Enfant Plaza N SW 950 L'Enfant Plaza Washington, DC 20024				13. Type of Report and Period Covered Final Report	
				14. Sponsoring Agency Code AFS-300	
15. Supplementary Notes The FAA William J. Hughes Technical Center Aviation Research Division COR was David Westlund.					
16. Abstract The increasing use of composites in commercial aerospace requires an integrative strategy with regard to composite materials training and the transfer of technology knowledge to the workforce. Though considerable training resources exist, no universally accepted standards for training have been developed until recently. This paper outlines the training framework for a basic composites course and a composites apprentice course specifically for repair work.					
17. Key Words Composite Materials, Training, Safety, Curriculum, Repair			18. Distribution Statement This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161. This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov .		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 31	22. Price

TABLE OF CONTENTS

	Page
EXECUTIVE SUMMARY	vi
1. GENERAL INTRODUCTION AND RESEARCH BACKGROUND	1
2. PART ONE: BASIC COMPOSITES CURRICULUM	2
2.1 Introduction to Composites (Composite Applications)	2
2.2 Composite Materials	4
2.3 Composite Manufacturing	4
2.4 Composite Fabrication	5
2.5 Composite Inspection (Ultrasonic NDI)	7
2.6 Composite Repair	8
3. PART TWO: COMPOSITES REPAIR CURRICULUM	9
3.1 Adhesive Bonding Guidelines	10
3.2 Problem Solving: “What is it for Composite Repair”	10
3.3 Metal and Electrical Bonding Techniques	11
3.4 Compare and Contrast of Bolted and Bonded Joints	11
3.5 Process Associated With Bolted Repair	11
3.6 Variety of Complex Repairs Demonstrated	12
3.6.1 Variety of Complex Repairs Demonstrated: Option 1	13
3.6.2 Variety of Complex Repairs Demonstrated: Option 2	13
3.6.3 Variety of Complex Repairs Demonstrated: Option 3	13
3.7 Overall Repair Process	14
3.7.1 Overall Scarf Sanding	14
3.7.2 Taper Sanding	15
3.7.3 Step Sanding	15
3.7.4 Simple Abrasion	16
3.7.5 Scarf Cleaning	16
3.7.6 Panel Drying	16
3.8 Honeycomb Core Repair Process	16
3.9 Solid Laminate Repair Process	18
3.10 Repair Curriculum Practicum Overview	19
3.10.1 Repair Curriculum Practicum	19
3.11 Repair Curriculum Practicum Grading Recommendations	20
3.12 Conclusion	21

4. REFERENCES

22

APPENDICES

A—BASIC COMPOSITES CURRICULUM

LIST OF ACRONYMS

AC	Advisory Circular
AMT	Aviation Maintenance Technician
NDI	Nondestructive inspection
OEM	Original equipment manufacturer
PDCA	Plan Do Check Analysis
PPE	Personal protective equipment

EXECUTIVE SUMMARY

The increasing use of composites in commercial aerospace requires an integrative strategy regarding composite materials training and the transfer of technology knowledge to the workforce. Though considerable training resources exist, no universally accepted standards for training have been developed until recently. This paper outlines the training framework for a basic composites course and an apprentice course specifically for composites repair work.

The first task was to develop a Basic Composites Curriculum that would accompany the current Aviation Maintenance Technician certification. This course is approximately 1 week in length and rather short and simple in terms of content. No hands-on or laboratory time is involved with this curriculum. Rather, the course provides an overall elementary knowledge of composites and supplements the Advisory Circular 147 revision, which is currently underway.

The second task was to develop a Composites Repair Curriculum, an apprentice course based entirely on composites repair techniques, including the following: identification of basic damage, different repair methods, and a practicum. The curriculum also thoroughly outlines a honeycomb core sandwich repair and a solid laminate repair. The coursework takes much longer than 1 week to be administered successfully and includes class work, hands-on time, and demonstration. Once a student completes this coursework, an employer would have a very good understanding of the level of composites repair that the student would be able to provide.

1. GENERAL INTRODUCTION AND RESEARCH BACKGROUND

The focus of this research was to develop the content to support a composite maintenance awareness course structure for use across the aviation industry. This course curriculum will accompany the Advisory Circular (AC) 147-3B to assist persons in earning an Aviation Maintenance Technician (AMT) certification. The framework of the course structure is focused on maintenance of an aircraft/airframe, but with an emphasis on composites.

This research consists of two parts. The first, Basic Composites Curriculum, will accompany the AC 147-3B current coursework for AMT certification but with an added composites emphasis. The coursework here is brief, simply to provide a general understanding of composites. The duration of this course is approximately 1 week, as a minimum. The second part of this research is a comprehensive Composites Repair Curriculum with key training points and a practicum to be given to the student on completion of the course.

The AC 147-3B defines three teaching levels, which the proposed curriculum follows. Part 1 of this research, the composites curriculum coursework, is considered Level 1, with no practical applications required. Part 2 of this research, the repair curriculum, consists of Levels 1, 2, and 3. The repair curriculum defines general principles, provides hands-on application, and requires a practicum once the course is completed, to demonstrate the required skills that were learned:

“Level 1 requires knowledge of general principles and instruction by lecture, demonstration, and discussion, but no practical application or development of manipulative skill. Teaching aids or instructional equipment may include charts, books, diagrams, or other visual teaching aids. If an AMTS chooses to teach level 1 course incorporating actual components, the components do not have to be operational.

“Level 2 requires knowledge of general principles, limited practical application, and development of sufficient manipulative skill to perform basic operations, as well as instruction by lecture, demonstration, discussion, and limited practical application. This teaching level requires some hands-on manipulative skills and their accompanying actual or simulated components/ equipment, but still may be taught primarily in the classroom environment.

“Level 3 requires knowledge of general principles, performance of a high degree of practical application, development of sufficient manipulative skills to simulate return to service, and instruction by lecture, demonstration, and discussion. This teaching level requires hands-on manipulative skill as well as sufficient and appropriate instructional aides to train the student to develop manipulative skills sufficient to simulate return to service. At this level, the teaching aids must be similar to, or the actual items of, equipment on which the student is expected to develop required skill levels. A level 3 subject cannot be taught solely by lecture in the classroom; the appropriate training aids and hands-on experience must be used” [1–8].

2. PART ONE: BASIC COMPOSITES CURRICULUM

The following is an outline of the recommended Basic Composites Curriculum to accompany AC 147-3B. This curriculum provides the student with a basic understanding of composites, from raw materials to part fabrication, handling, storage, and repair. Included are definitions and an understanding, as required for Level 1; no examples or hands-on/practicum are required with this basic curriculum. The Basic Composites Curriculum consists of the following six key sections:

1. Introduction to Composites (Composite Applications)
2. Composite Materials
3. Composite Manufacturing
4. Composite Fabrication (Finish Trim/Assembly)
5. Composite Inspection (Ultrasonic Nondestructive Inspection [NDI])
6. Composite Repair (Hot Bonding, Electrical Bonding, Bolted Joint)

These six key sections are discussed in sections 2.1–2.6, detailing the main curriculum points to be taught. Each section has the appropriate descriptions necessary to be taught for the principles to be understood by the students.

2.1 INTRODUCTION TO COMPOSITES (COMPOSITE APPLICATIONS)

This section reviews the fundamentals of composites and current composite applications. Here, the goal for students is to identify the terminology, tools, equipment, and materials used within the composites industry. Eight key sections will be covered to achieve this goal. Each of the following bullets identifies the key teaching component; the sub-bullets identify the key definitions or explanations to be understood by the student:

- What is a composite?
 - A composite is two or more materials (constituents) combined to form a single material. Leaving this course, the definition of composite is a material consisting of high-strength fibers held together in a polymer matrix.
- Why do we use composites vs. other engineering materials?
 - Compared to typical metals, composites have high strength, are lightweight, have a high stiffness-to-density ratio, are corrosion resistant, increase design flexibility, and have higher fatigue strength.

- What are the safety standards associated with the composites industry, including personal protective equipment (PPE) and disposal of composite materials?
 - Composite scraps, prepreg materials, and remnants from wet lay-up must be cured and disposed of. No lotions or oils of any kind are permitted around the use of prepreg, resin, or release systems. Gloves and safety glasses are required for manufacturing with composites, and special cutting gloves are recommended when cutting composites. Ventilation masks are not required but strongly encouraged.
- What is the brief understanding of current composite uses in aerospace industry?
 - Today, composites are commonly found in brackets, fuselages, bulkheads, wings, skins, spars, tooling, and backup structures. Outside the aerospace industry, they are often found in boats and sports equipment.
- What is a “clean room?”
 - A clean room is a room that has the capability of monitoring and controlling temperature, humidity, and sometimes particle count. Different composite materials and different manufacturing facilities have varying clean room requirements. Temperature and humidity are needed because composites are sensitive to moisture.
- What is the material shelf life/out time of composites?
 - The shelf life of composites refers to the lifetime the prepreg or resin system can withstand a controlled environment (e.g., a freezer at 0°C), typically for 1 year. The out time is the length of time the material can withstand a controlled environment, typically 10 days, at a maximum temperature of 80°F. After 10 days, the material needs to be cured per manufacturer instructions. Both shelf life and out time durations can fluctuate based on the material manufacturer.
- What is the protocol for composite material storage and handling?
 - All composite parts shall be handled in a manner as to prevent breakage, stretching, twisting, warping, gouging, scratching, or any other change in the shape or condition of the part surface. Special attention must be given to certain critical items, such as exterior skins, honeycomb core, bonded assemblies, and machined parts. Transportation and handling equipment, containers, and protective packaging techniques suitable for protection of such items from damage are required. Covering the surface during any transportation in which ultraviolet light exposure is a possibility is recommended so that no damage occurs to the composite material, even after being cured.

2.2 COMPOSITE MATERIALS

The goal of this section of the curriculum will be for students to compare and contrast materials associated with the composite industry.

- Identify different structural materials:
 - Fibers: fiberglass, Kevlar[®], aramid, carbon fiber, graphite
 - Core materials: foams, honeycomb, fiberglass core

- Identify the following relative to fiber materials:
 - Warp/fill direction, warp face, nesting, stacking sequence, fill threads, and salvage edge on weave material
 - Material drape, types of weave (twill, plain, satin), weave styles, 2x2 twill, and 4-, 5-, and 8-harness satin/crowfoot
 - Unidirectional tape, important manufacturing qualities, identifying and handling unitape versus fiber
 - Ply orientation (balanced, unbalanced, symmetrical, and quasi-isotropic)

- Understand the following key characteristics of resins:
 - Resin types (thermoset, epoxy, phenolic, thermoplastic, thermoforming)
 - Describe the role of resin/matrix system in composites
 - Describe resin system properties for different resin systems
 - Identify cure temperature ranges for different resin systems (most common)
 - Explain the glass transition temperature principle

2.3 COMPOSITE MANUFACTURING

The goal of this section of the curriculum is for students to understand the different manufacturing techniques and identify key composite manufacturing principles:

- Identify the following key components for composite manufacturing:
 - Tooling: layup process tools, shop tools, tooling molds, and tooling masters
 - Surface preparation (tooling): release agents
 - Bagging system materials: peel ply, perforated and non-perforated fluorinated ethylene propylene, breather, bleeder, vacuum ports, tacky tap, and pressure plates
 - Vacuum system, ports, gauge, pump, and hose
 - Recording vacuum, measuring vacuum, and performing leak checks

- Understand the significance of the cure process:
 - Room temperature, elevated temperature, ramp, dwell, soak, and cool down
 - Thermocouples and their placement on a part respective to a vacuum bag
 - Curing equipment and their differences (oven/autoclave)
- Understand the different manufacturing methods:
 - Thermoset processing, thermoplastic processing, prepreg lamination, wet lay-up, spray-up, resin transfer molding, vacuum-assisted resin transfer molding, filament winding, fiber placement/automated tape laying, pultrusion, and adhesive bonding
- Understand the difference between sandwich composites and laminates:
 - Identify the role of the core in sandwich composites
 - Identify primary types of core and foam materials and their properties
 - Identify the different applications for core materials
 - Understand key difference with manufacturing sandwich parts/panels solid laminates

2.4 COMPOSITE FABRICATION

The goal of this section of the curriculum is for the students to be able to handle a composite part post cure without damaging the part or injuring themselves. This section has three subcategories (finish trim, assembly, and paint), which are all relevant to composite fabrication.

In learning the finish trim process in composite fabrication, the student will be able to apply safety standards to the net trim process and identify different trim processes and trim tools for different fibers:

1. Apply safety standards, use all appropriate PPE, and dispose of waste materials.
2. Inspect the composite part:
 - a. Determine if there is any core damage, holes, delamination, resin damage, fluid intrusion, or contamination. Identify the peel ply used, if any.
3. Trim the composite part:
 - a. Use the trim process for different fibers: aramid, fiberglass, carbon fiber, hybrid.
 - b. Use trim tools: razor blade, scissors, band saw, router bit, diamond router bit, dual-action sander, 90- or 100-degree DOTCO grinders, drill press.
 - c. Locate trim lines per planning paper/engineering drawing.
 - d. Place trim lines using multiple methods including template, measurements, or tolerance per engineering drawing.
 - e. Select appropriate trim tool, which is dependent on type of composite material, as well as thickness, length, width, contour, and type of peel ply.

4. Prepare the composite surface (critical post-cure steps):
 - a. Remove peel ply
 - b. Remove post peel ply: dry wipe, solvent (double) wipe
 - c. Sand a composite surface: sandpaper, Scotch-Brite™
 - d. Select the timeframe post sanding before paint is applied

Composite fabrication assembly will teach students the basics of joining composite structures, covering both adhesive and mechanically fastened processes. The overall goal for students is to have awareness of assembling composites post cure:

1. Use the planning paper/engineering drawing to determine type of makeup of part materials (Kevlar, fiberglass, carbon fiber, or hybrid).
2. Understand the key principles of drilling:
 - a. Recognize drilling tools, including drill bits, dagger drill, diamond-coated cutting tools, hole saws, grinding tools, and routing bits.
 - b. Use layout techniques (PVA templates) to identify fastener locations.
 - c. Understand how to use heat tape (adhesives) and when this would be required.
 - d. Learn how to select the appropriate drill bit for composite material being drilled (color coding used for drill bits).
 - e. Learn how to avoid delamination/separation during drilling.
 - f. Use the appropriate speed and feed rates of the drill for composites.
 - g. Understand the impact of friction from drilling on matrix/resin system.
 - h. Identify the process for drilling a perpendicular hole.
3. Recognize the fasteners for mechanically fastening two pieces together and for supporting an existing structure:
 - a. Identify fastener types: inserts, threaded fasteners.
 - b. Identify tools used for installation per fastener type: click bond, cherry type, pull type.
 - c. Identify potting material and the mixing process for potting material.
 - d. Identify the process of reinforcing fasteners (drill, insert potting material, re-drill).
 - e. Learn when to use countersink fasteners.
 - f. Understand the difference for countersinking fasteners in composite vs. aluminum (120-degree, 130-degree, and 100-degree fastener types).
4. Understand the advantages and disadvantages of co-curing/co-bonding with composites.

The final stage of composite fabrication is applying paint. The goal of this section is to help students to understand the painting process and the significance of surface preparation, the detriments of applying too much paint, and the unique differences between applying paint to a composite versus a metallic part:

1. Learn how to control paint thickness on a composite:
 - a. Limit thickness to no more than 5 ml
 - b. Do not strip and repaint, as with aluminum

2.5 COMPOSITE INSPECTION (ULTRASONIC NDI)

The goal of this section of the curriculum is for students to perform basic NDIs of composite components using the equipment and processes associated with the NDI/composites industry:

- Identify documentation requirements for composite inspection:
 - Identify manuals/documents used in the inspection process.
- Define NDI, and identify the history and evolution of NDI:
 - Identify the types of damage that each NDI technique will detect.
 - Identify the reliability of NDI testing techniques: probability of detection.
- Identify NDI equipment and testing techniques including tap test, x-ray, ultrasound, thermography “exotic methods:”
 - Demonstrate tap test and ultrasound test.
 - Compare/contrast tap test results with more advanced NDI testing techniques.
- Identify differences in in-service inspection vs. production inspection:
 - Identify the repair technician’s role in the inspection process.
 - Identify the role of quality assurance and engineering in the inspection process.
- Identify typical points of inspection during a repair procedure, including before repair, damage removal, bagging, cure/setup, repair completion, structural inspection, and ready for finish:
 - Identify the value of inspection points.
 - Identify the potential process at each inspection point, including a return to NDI or adjustment to repair process.
 - Identify terminology including standard repair and Material Review Board authorized repair.

- Identify damage-assessment techniques:
 - Identify entry point for damage detection by visual search including lightning strike, bird strike, and scheduled inspection.
 - Demonstrate visual damage/defect assessment techniques.
 - Identify industry standards for determining damage levels, including negligible or cosmetic and repairable or not repairable.

2.6 COMPOSITE REPAIR

Three types of composite repair are discussed in this curriculum: hot bonding, electrical bonding, and bolted joint. The goal is for students to understand the purpose of structural repairs and for them to be able to recommend if the repair needed is a primary or secondary structure repair.

The hot-bonded repair of a composite involves the following: repair plies to overlap and evenly distribute the load from the structure to the repair patch. The repair plies are bonded to the structure, usually with an adhesive layer between each repair ply. A heating element (oven, autoclave, or an approved portable device, such as a heating blanket) then cures the repair to the structure:

1. Identify materials used in structural repair (prepreg or wet layup).
2. Understand the key steps for prepreg or wet layup repair:
 - a. Apply cleaning processes and debagging techniques.
 - b. Identify the appropriate order of layup, mixing ratio of the material, and role of warp.
 - c. Create a template of each ply step (bagging film), and identify time-saving techniques when bagging, including pre-set bagging before plies and use of Mylar for ease of clean up.
 - d. Understand types of core for repair, and cut a core using appropriate methods.
 - e. Cut plies according to a template, and understand appropriate storage techniques for templates.
 - f. Define zero axis of the part.
 - g. Identify wet layup, flush patches, prefit core in replacement area, etc.
 - h. Understand bagging techniques, bonding techniques, and several industry adhesives used for repair.
 - i. Identify the type of cure: room temperature with post cure, elevated cure, etc.
 - j. Understand other curing tools used in repairs: heat blankets and heat guns.
 - k. Identify different vacuum techniques with repairs.

The goal of learning an electrical-bonded repair on a composite is for students to be able to identify the primary role and significance of electrical bonding during composite repair:

- Learn about electrical bonding:
 - Define the relationship (electrical continuity) between the base part and the repair.
 - Comprehend the terminology of electrical-bonding repair, including Ohms), the unit of electrical resistance.
 - Identify the acceptable standards and how to locate them for electrical bonding.
 - Become familiar with the types of materials used in electrical-bonding repair (stainless steel, nickel coated, aluminum foil, expanded copper mesh, and expanded aluminum mesh).
- Use/read a multi-meter to determine if electrical continuity exists.
- Identify appropriate adhesive to use for electrical bonding repair.
- Learn how to check for the electrical bond:
 - Use the process of layup or wet layup, bagging, and curing on two composite parts with fasteners, including metal and jumper wire.

With a bolted-joint repair on a composite, the student's goal is to be able to identify the primary role and significance of bolted-joint repairs and to be able to identify which repair may be the best option during in-service use:

- Learn about the bolted-joint repair, its advantages and disadvantages, and preparation for the repair.

3. PART TWO: COMPOSITES REPAIR CURRICULUM

This curriculum will teach the student to identify basic damage to a composite part, perform a scarf repair to the damaged area, and demonstrate this through the use of a practicum. This curriculum provides a realistic definition for what the student can perform for industry once completed with this coursework.

The primary focus of this coursework is safety with respect to repair work, specifically on an original equipment manufacturer (OEM) part. The student will acquire basic knowledge and skills with respect to identifying and performing a repair on a composite part. Three basic skills that the student should have after this coursework are:

1. How to read an engineering drawing
2. How to perform a composite scarf repair
3. How to explain/justify the repair to the appropriate governing body

The practicum accompanying this curriculum encompasses the skills learned and allows the student to demonstrate the content in a measurable way.

This curriculum is intended to provide the students with hands-on experience with composite repairs for non-structural parts. It also outlines problem-solving techniques. The primary outcome of this curriculum is that students will be able to repair composite components for the composite industry using materials and processes.

3.1 ADHESIVE BONDING GUIDELINES

Structural joints transfer load from one component to another. Adhesives offer good shear strength; therefore, joints are designed to ensure that load transfers in shear for a repair. The peel strength and tensile strength of adhesive joints are not very good.

Mechanical joints (bolted or riveted) offer a higher peel strength and tensile strength than adhesive joints. So when an adhesive joint is used to replace a mechanical joint, an adequate design must be considered for the composite structure. Tensile compressive and shear stresses are easier to identify in composite applications; when analyzing a joint/bonded area, peel stresses are less easy to identify. Peel stresses often occur when the edges of the joint are subject to bending. If a substrate is too flexible, then occasionally tensile and shear stresses can also be translated into peel stresses when the applied loads are not parallel with each other.

Design guidelines for a good adhesive bond are as follows:

1. Allow the joint to have a load transfer in the shear or compressive mode.
2. Critically select the adhesive, accounting for temperature resistance, chemical resistance, and overall strength needed.
3. Ensure that joints are user friendly, meaning the bond area is easily accessible by technicians for adequate surface preparation.
4. Maximize the adhesive bonding area by using the largest area possible so that stresses induced in the joint are minimal.
5. Carefully consider joint design; joining dissimilar metals creates thermal expansion and contraction stresses.
6. Optimize the adhesive thickness to achieve the best bond strength; adhesives that are too thick or too thin will create a poor bond strength. Also, use adequate adhesive to wet the entire joining surface.

3.2 PROBLEM SOLVING: “WHAT IS IT FOR COMPOSITE REPAIR?”

Problem-solving techniques are useful in many different situations, but they are also highly recommended in a composite repair situation. The most common problem-solving technique used in industry is the Plan Do Check Analysis (PDCA) model. This curriculum should take the student through the PDCA model, reviewing its elements, completing all documentation, and applying it.

3.3 METAL AND ELECTRICAL BONDING TECHNIQUES

The following is the curriculum for metal- and electrical-bonding techniques:

1. Identify metal-bonding techniques:
 - Identify dissimilar metals.
 - Determine elements of metal bonding and dissimilar metals to be repaired.
2. Learn about electrical-bonding techniques:
 - Determine the elements of the electrical-bond repair bonding area.
 - Review case studies for electrical-bonding repair.
 - Compare and contrast good and bad electrical-bond repairs.

3.4 COMPARING AND CONTRASTING BOLTED AND BONDED JOINTS

This curriculum teaches students how to compare and contrast bolted and bonded joints:

- Identify the role of the bolted-joint repair, and ensure that the student can identify this role in the entire repair process for composites.
- Identify the reasons why bolted repair would be the preferred repair method.
- Compare and contrast a bolted joint vs. a bonded repair joint, including the following:
 - Anisotropic behavior
 - Fastener deformation
 - Fastener clearance
 - Fastener clamp-up
 - Low z-directional strength

3.5 PROCESS ASSOCIATED WITH BOLTED REPAIR

Students should be able to understand these items and demonstrate the descriptions indicated below. This section of the curriculum consists of classroom instruction, instruction or demonstration with training aids, and hands-on time required to practice certain skills:

- Identify equipment and materials used in bolted repair.
- Identify and demonstrate surface-preparation techniques associated with bolted repairs.
- Identify the steps to prepare the “doubler” material used for the repair (including measurement, cutting, and deburring of edges), and demonstrate the doubler preparation technique.
- Identify and demonstrate the transverse pitch.
- Identify the fastener diameter-to-edge distance:
 - Calculate the edge distance with 2D minimum and 4D maximum.
 - Maintain 4D edge distance during the fastener installation process.

- Identify and demonstrate the techniques for layout of a fastener pattern.
- Identify the issues associated with corrosion and fasteners in composite repairs.
- Identify drilling issues associated with composite parts (including drill speed and fiber breakout):
 - Demonstrate hole-preparation procedures associated with composite parts, including pilot holes and associated drilling pattern, step-drilling, reaming, and deburring.
- Identify fastener selection used for bolted repair.
- Identify and demonstrate fastener installation techniques, including temporary fasteners and blind fasteners.
- Identify the role of sealant in a bolted repair, and demonstrate the sealant application process, including fastener wet install.
- Demonstrate bolted repairs in a variety of materials, including solid laminate and honeycomb or sandwich structures.

3.6 VARIETY OF COMPLEX REPAIRS DEMONSTRATED

This section of the curriculum requires students to be able to understand a variety of complex repairs and demonstrate the following steps. This section of the curriculum consists of classroom instruction, instruction or demonstration with training aids, and hands-on time required to practice certain skills.

Once a repair is needed, the following steps should be taken to begin several complex repairs:

1. Identify the role of a nonstructural repair.
2. Identify the basic types of nonstructural repairs, including sealing, potting, resin injection, cosmetic defects, and laminating.
3. Compare contrast tolerances and orientation requirements in structural and cosmetic repairs.
4. Identify the cosmetic standard used for repair.
5. Identify the standard repair manual.
6. Identify the role of the standard repair manual in determining the size and quantity of the defects, and define the types of cosmetic defects.
7. Identify why sandpaper selection impacts repair:
 - a. Compare and contrast the results from using different types of sandpaper.
 - b. Identify the impact of using too-coarse of sandpaper (texture).
 - c. Identify the impact of using too-fine sandpaper (low surface energy).
8. Identify other common materials.
9. Develop a PDCA plan for a complex repair project.

Once the repair goal is understood, the techniques in sections 3.6.1–3.6.3 should be understood and able to be demonstrated and applied.

3.6.1 Variety of Complex Repairs Demonstrated: Option 1

The following is the first option for demonstrated complex repairs:

1. Identify procedures for cosmetic repairs, including surface porosity, resin starvation, edge erosion, delamination, single-ply damage, and cosmetic finish:
 - a. Demonstrate abrasion techniques to the repair site, and apply resin.
 - b. Demonstrate smoothing techniques, including filling holes.
 - c. Demonstrate curing techniques.
 - d. Demonstrate sanding techniques.
2. Evaluate the repair to determine if additional work is required.

3.6.2 Variety of Complex Repairs Demonstrated: Option 2

The following is the second option for demonstrated complex repairs:

1. Identify types of abrasion:
 - a. Demonstrate abrasion techniques to the repair site.
2. Identify types of resin, including thickening agents and fairing compound:
 - a. Apply resin.
 - b. Demonstrate smoothing techniques, including filling holes.
 - c. Demonstrate curing techniques.
 - d. Demonstrate sanding techniques.
3. Evaluate the repair to determine if additional work is required.

3.6.3 Variety of Complex Repairs Demonstrated: Option 3

The following is the third option for demonstrated complex repairs:

1. Identify edge erosion.
2. Identify causes of edge erosion:
 - a. Demonstrate smoothing techniques, including filling holes.
 - b. Demonstrate sanding techniques.
 - c. Demonstrate sealing techniques with adhesive.
 - d. Demonstrate sealing techniques with resin.

3. Recognize need to wrap with ply:
 - a. Demonstrate wrap with ply techniques.
4. Evaluate the repair to determine if additional work is required.

3.7 OVERALL REPAIR PROCESS

This repair procedure is similar to that found in many industry standard repair manuals for many different OEMs, referencing the relevant SAE Commercial Aircraft Composite Repair Committee standards. This procedure was reviewed and approved by various technical monitors and industry points of contact.

Some basic key features to starting a repair need to be understood, including understanding the part drawing that shows exactly where the repair needs to occur. This drawing needs to contain directions so that it is clear where the damage is and the direction of the ply orientation and core ribbon, if applicable. These directions are key to making the new repair, because the material applied and the core plug must be in the same orientation as the parent part.

The environment is an important consideration for repairs. Repairs must occur in a clean room, but there are still temperature and humidity constraints to be observed. When performing a repair, the following needs to be recorded at the start and end of the repair: date, time, temperature, and relative humidity.

Most repairs are completed using a repair kit provided by the production facility so that the repair material fiber and adhesive are cohesive with the parent material system used. The repair kit should contain the following: material type, date of shipment, batch/roll, manufacture date, expiration date, original out life, and remaining out life. Within the kit there should also be instructions for thawing the material and the necessary information on storage life and out time for the material in the kit, when relevant. Also within the kit for which a prepreg repair is being completed, there should be prepreg and adhesive ply dimensions with ply orientation noted.

Panel masking is the process used to protect the undamaged part area. Using an approved tape and some Kraft paper, the goal here is to cover the undamaged area to minimize debris that is exposed to the rest of the part.

3.7.1 Overall Scarf Sanding

Three types of abrasion techniques are acceptable for scarf sanding in a honeycomb repair: taper sanding, step sanding, or simple abrasion. Typically, repairs on thicker laminates, which are intended to restore structural load carrying capability, or repairs on aerodynamic surfaces involve the taper sanding or step sanding technique. Bag side repairs, smaller repairs that are not intended to restore the original load-carrying capability, and repairs to thinner laminates typically involve the simple abrasion technique. Taper and step sanding techniques use handheld devices, which require more skill than automatic and semi-automatic equipment. Some OEMs have a specified repair manual based on their material system, which may provide other details than what those

contained here. If the repair manual does not specify details, then the values provided here would be the safe alternative:

3. Machine the taper or step with 8-grit or finer abrasive paper.
4. Use 150-grit or finer abrasive paper on the final surface preparation.
5. Identify, mark, and mask off the area not to be sanded.
6. Mark with colored pencils and felt tip markers approved for contact on the composite surface.

Solid laminate sanding requires a backing plate for the backside to prevent damage and fraying at the thin edge. The plate is attached with double-sided sticky tape. The backing plate can consist of a material stiff enough to support the thin edge of the solid laminate material.

3.7.2 Taper Sanding

Taper sanding is a step that needs to be taken very carefully. Different parts may require a different slope, and this would be outlined in the repair document and identified previously by engineering:

1. Start at the center of the damage location and remove the damage through the thickness.
2. Gently and slowly move to the outer ply one ply at a time until the final repair size is obtained.
3. Do not sand through the entire skin or laminate unless the damage extends through the entire thickness of the part.
4. For laminates, begin sanding the edge of the damage cleanup hole to an edge that is approximately the thickness of the bottom ply.
5. Note that sandwich parts typically have a taper resembling a knife edge at the top of the core.
6. Continue sanding the taper area, working from the center of the damage area to the top of the outline, previously marked as the repair area.
7. Once sanding is completed, ensure that the tapered area is free of delaminations and has a smooth, constant slope.
8. Clean the areas thoroughly, removing all dust; vacuum, if needed.

3.7.3 Step Sanding

The procedure for step sanding is a bit more tedious. The process starts at the outer edge of the final repair size, removing each ply one by one. Once the plies are removed, the sanding is then continued inward until all damage is removed. When machining, it is critical to remove only material in the ply being removed, not the underneath plies, which would impact the overall strength of the part:

1. Determine the number and width of the plies to be machined into the part; this is the number of plies to be replaced, minus one.
2. Starting at the outer edge of the repair, machine the steps, working down to the center of the perimeter of the outline repair area.
3. Once completed, clean the stepped area well, removing all dust and debris (once clean, the stepped area should resemble an evenly spaced, stepped area).

3.7.4 Simple Abrasion

The procedure for simple abrasion is as follows:

1. Determine the width of the ply to be removed from the damaged part.
2. Starting at the outer edge of the ply, lightly abrade using sand paper, working down to the center of the perimeter of the outline repair area.
3. Once completed, clean the area well, removing all dust and debris (once clean, the repair area should resemble one ply removed from the identified repair area).

3.7.5 Scarf Cleaning

Scarf cleaning is very important after any sanding technique. It is critical to remove all debris from the sanded area prior to proceeding with any repair. Solvent wiping is sometimes permitted also, to aide in collecting all sanded debris from the part. A water break test is recommended and used after the damaged area is sanded and free of debris. The water break test shows if there is debris or solvent that has not been properly removed. This is done by dripping a small amount of water onto the cleaned surface; if the water beads, this is a clear sign of debris remaining on the surface.

3.7.6 Panel Drying

Panel drying is a critical step that is completed prior to bonding of any kind. Panel drying ensures that all moisture has been removed from the damaged and sanded areas, thereby creating a good bonding surface. Trapped water prior to bonding will impact the quality of the bond created on the part. Panel drying is done at a low temperature so no damage occurs to the rest of the part or backup structure. The panel drying temperature is determined by the material system from which the part was made and the remaining part structure.

3.8 HONEYCOMB CORE REPAIR PROCESS

This section shows the sequence of repairs for a honeycomb part damaged through the core. This repair process can fix the damaged part and the damaged core area using a scarf repair technique with a wet lay-up patch. The process outlined here is adequate for fixing a sandwich panel without damage caused to the honeycomb core, if this can be verified:

1. Obtain a drawing of the part showing the location of damage and the inner and outer scarf boundaries.
2. Record the repair environment date, time, temperature, and relative humidity at the start and end of the repair.
3. Record the repair kit information material type, date of shipment, batch/roll, manufacture date, expiration date, original out life, and remaining out life.
4. Identify the laminating resin being used, and note the storage life and out time.
5. Identify the dry fiber sizes required for the repair area.
6. Begin marking the panel with the area to be repaired, and mark the fiber orientation of the parent panel material.
7. Mask panel areas around the repair that do not require repair.

8. Scarf the damage area by removing the damage and stepping the plies away from the damage area.
9. Clean the scarf area with proper solvents.
10. Measure the core depth and the filler ply area.
11. Perform a water break test to validate that the area is clean of contaminants and ready for repair.
12. Dry the repair panel prior to repairing.
13. Perform a final cleaning of the repair area (repair must be completed within 20–30 minutes after final cleaning).
14. Follow repair layup instructions:
 - a. If the previous core in a sandwich panel was damaged and removed, then obtain a core plug for the damage area. If the original core was not damaged and removed, then skip to Step h.
 - b. Restore the core of the damaged sandwich panel using a high-strength laminating resin. In the aerospace community, EPOCAST 52 A/B is the most common resin used to bond the core plug to the existing skin and core.
 - c. Apply a high-strength laminating resin to the existing core plug and core interface until they are completely wet with resin. Place the core plug in the damaged area. Take a picture of the core plug to display its ribbon direction and the original panel ribbon direction.
 - d. Vacuum bag both sides of the repair panel, including both the damaged and undamaged areas; if this is not possible, then use an envelope bag to vacuum bag the entire panel.
 - e. Apply the vacuum to both sides of the panel, and cure the core plug. The suggested cure cycle is as follows: ramp 1°–5°F per minute to 270°F and dwell for 120 minutes; ramp down at a rate of 1°–10°F per minute. This cure cycle may be altered slightly based on the high-strength resin used.
 - f. Inspect the core post cure using visual techniques and NDI tap tests.
 - g. Apply high-strength resin to the core splice bondline and any other areas not completely filled, and let it cure. A heat gun may be used gently to kick off the cure. If the use of a heat gun is permitted, then the heat gun should only be used for a maximum of 7 minutes.
 - h. Obtain the dry repair plies used for repair, which have been previously cut to size.
 - i. Using some plastic bag material and the dry plies, impregnate the repair plies with a laminating resin. For best results, do this one ply at a time, applying a small amount of resin to the dry ply and with a clean shop tool, such as a squeegee, saturate the dry ply with the resin. The ply should be wet with resin, but not dripping, when applied to the repair; it is key that there are no dry spots on the ply when applied to the repair.
 - j. Lay the first impregnated ply down on the repair surface, ensuring that all debris is removed from the repair area. Match the impregnated ply orientation with the parent laminate ply orientation.
 - k. Take a digital photo of the repair after each ply is applied.
 - l. Apply the remaining plies required for the repair.

15. Install thermocouples, the quantity of which may vary based on repair size. Envelope bags are recommended, but this could be done using a very good caul sheet that is free of scratches. The bagging technique would be a no-bleed process.
16. Cure the repair; this will be dependent on the laminating resin selected.
17. Perform NDI and tap testing.

3.9 SOLID LAMINATE REPAIR PROCESS

This repair process is valid for solid laminate panels or parts that have been damaged and need to be repaired via scarf repair with an adhesive layer and a prepreg material. This is one of the strongest repairs:

1. Obtain a drawing of the part showing the location of damage and the inner and outer scarf boundaries.
2. Record the repair environment date, time, temperature, and relative humidity at the start and end of the repair.
3. Record the repair kit information material type, date of shipment, batch/roll, manufacture date, expiration date, original out life, and remaining out life.
4. Thaw the repair kit, and pay attention to its storage life and out time.
5. Identify the repair kit information, prepreg, and adhesive ply dimensions.
 6. Begin marking the panel with the area to be repaired and mark the fiber orientation of the parent panel material.
6. Mask panel areas around the repair that do not require repair.
7. Scarf the damage area by removing the damage and stepping the plies away from the damage area.
8. Clean the scarf area with proper solvents.
9. Perform a water break test to validate that the area is clean of contaminants and ready for repair.
10. Dry the repair panel prior to repairing.
11. Perform a final cleaning of the repair area (repair must be completed within 20–30 minutes after final cleaning).
12. Follow repair lay-up instructions:
 - a. Measure the scarfed panel area to cut the film adhesive.
 - b. Use a film adhesive compatible with the base panel material and prepreg for repair, and apply it to the clean parent panel that is ready for repair.
 - c. Obtain the first prepreg ply and place it on the bottom of the scarfed area, aligning the orientation to the parent ply. Apply the prepreg plies one at a time starting from the bottom and working upward. In most cases, ensure that the bottom is closest to the tool side.
 - d. Take a digital photo after each ply is applied to the repair.
 - e. Debulk the first ply for 10–15 minutes.
 - f. Continue with steps d and e until all the prepreg plies have been used and the repair is finished.

13. Install thermocouples, the quantity of which may vary based on repair size. Envelope bags are recommended, but this could be done using a very good caul sheet that is free of scratches. The bagging technique would be a no-bleed process.
14. Cure the repair; this will be dependent on the laminating resin selected.
15. Perform NDI and tap testing.

3.10 REPAIR CURRICULUM PRACTICUM OVERVIEW

The repair curriculum is designed to challenge the student on various types of repairs, the key features of repairs, and different skills discussed. The following definitions should be considered when administering this practicum:

1. Identify—the item or process can be visually identified without being told.
2. Demonstrate—the process can be completed by the student.
3. Determine—using the information taught within this course and other practical experience, make the best executed decision for the situation.

3.10.1 Repair Curriculum Practicum

The purpose of this practicum is for the student to display knowledge learned through this coursework material. This practicum will reveal that a student, as an AMT, can perform the skills identified within this test. The results will feed industry expectations for the course:

Section 1:

- Identify delamination repair that requires a structural repair process:
 - Identify types of delamination within a repair.

Section 2:

- Determine which type of repair is required using a standard repair manual:
 - Demonstrate drilling techniques (both ends of the repair site).
 - Demonstrate injection (resin) techniques.
 - Demonstrate injection techniques between composite layers.
 - Demonstrate clamping techniques.
 - Demonstrate the structural repair process on a delamination repair, and determine if the situation is a sacrificial ply situation.
 - Demonstrate filling procedures.
 - Demonstrate sealing procedures.
 - Determine if the situation requires ply removal and replacement.
 - Demonstrate the ply-removal technique.
 - Demonstrate ply replacement per structural repair techniques.
 - Demonstrate sanding skills to remove the finish.

Section 3:

- Apply problem-solving skills to determine if a part is actually damaged or just needs to be refinished:
 - Identify the step damage removal process.
 - Demonstrate the step damage removal process.
 - Identify the scarf removal process.
 - Demonstrate the scarf removal process.
 - Identify the plug removal process.
 - Demonstrate the plug removal process.

Section 4:

- Determine if the cosmetic finish needs cracks to be filled:
 - Demonstrate filler skills.

Section 5:

- Demonstrate a honeycomb core repair using the following:
 - Core plug removal technique
 - Scarf sanding technique
 - Wet lay-up repair patch

Section 6:

- Demonstrate a solid laminate repair using the following:
 - Scarf repair technique (machined steps)
 - Application of film adhesive
 - Prepreg repair material

This completes the practicum.

3.11 REPAIR CURRICULUM PRACTICUM GRADING RECOMMENDATIONS

The following are recommendations for grading the practicum's six sections:

1. Section 1: Student needs to be able to identify a delamination. This is critical in a repair that involves removing damage from a part, and is essential knowledge for a passing grade.
2. Section 2: Student needs to exhibit an understanding of what repair to use. If the student misses a couple of these, then the recommendation would be that the student passes, provided he or she is able to demonstrate the techniques in section 3.8.
3. Section 3: Student should demonstrate good problem-solving techniques to understand and be able to work through a problem. Here, the student needs to identify the process called

out to pass. This is more important than being able to demonstrate the process. With practice, the demonstration should become flawless, but without understanding, the steps and the practice will not be beneficial.

4. Section 4: This is a skill versus a necessary trait, but the student's understanding of the difference is more important than an exact demonstration of the skill.
5. Sections 5 and 6: Students must pass these two most important sections of the practicum, the proper demonstration of a honeycomb core repair and the proper demonstration of a solid laminate repair. These two demonstrations involve skills and processes that encompass several composite techniques, which will make the student a good technician in industry.

3.12 CONCLUSION

This project consisted of developing two curriculums. The first is a Basic Composites Curriculum to be completed within 1 week and involving no hands-on laboratory time, demonstrations, or practicum. This curriculum will accompany the current Aviation Maintenance Technician certificate, with a composites introduction, and will be part of Advisory Circular 147-3B. The curriculum will provide the student with a basic understanding of composites, including raw materials, part fabrication, part handling, storage, and repair. This basic curriculum on composites provides the definitions and understanding as required for a Level 1 understanding. It consists of the following six key sections:

1. Introduction to Composites (Composite Applications)
2. Composite Materials
3. Composite Manufacturing
4. Composite Fabrication (Finish Trim/Assembly)
5. Composite Inspection (Ultrasonic Inspection Nondestructive Inspection)
6. Composite Repair (Hot Bonding, Electrical Bonding, Bolted Joint)

The second phase of this project is the Composites Repair Curriculum for an apprentice-level technician, including a practicum for assessing the technician's skills upon completion. This curriculum consists of classroom time, demonstrations, and hands-on experience to teach the principles of composites repair. Here, the student will be able to identify basic damage to a composite part, perform a scarf repair to the damaged area, and demonstrate a repair through means of a practicum. Once the course work is completed, this curriculum provides a rigid definition for what the student can perform for industry. The student should have three basic skills after taking this coursework:

1. How to read an engineering drawing
2. How to perform a composite scarf repair
3. How to explain/justify the repair to the appropriate governing body

The practicum accompanying this curriculum encompasses the skills learned and allows the student to demonstrate the content in a measurable way. The primary outcome with this curriculum is that students will be able to repair composite components using materials and processes for the composite industry.

4. REFERENCES

1. FAA. (2015). Advisory Circular AC147-3B. *Certification and Operation of Aviation Maintenance and Technician Schools*, Washington, D.C.: Government Publishing Office.
2. SAE Aerospace. (2009–2010). *Critical Issues in Composite Maintenance and Repair*. (AIR5719).
3. SAE Aerospace. (2015). *Machining of Composites Materials, Components and Structures*. (AIR5367).
4. SAE Aerospace. (2011). *Drying of Thermosetting Composite Materials*. (ARP 4977).
5. Mazumdar, S. K. (2002). *Composite Manufacturing: Materials, Product and Process Engineering*, FL: CRC Press.
6. Mathews, F. L. & Rawlings, R. D. (1999). *Composite Materials: Engineering and Science*, FL: CRC Press 1003.
7. FAA. (2004). Bonded Repair of Aircraft Composite Sandwich Structures (DOT/FAA/AR-03/74).
8. SAE Aerospace. (2011). *Masking and Cleaning of Epoxy and Polyester Matrix Thermosetting Composite Materials*. (ARP 4916).

APPENDIX A—BASIC COMPOSITES CURRICULUM

Table A-1. Basic composites curriculum

Non-Metallic Structures		Level
1	Introduction to Composites (Composite Applications)	1
	1a What is a composite?	1
	1b Why do we use composites vs. other engineering materials?	1
	1c Identify safety standards associated with the composite industry including: PPE and disposal of composite materials	1
	1d Brief understanding of current composite uses in Aerospace industry	1
	1e What is a “clean room”?	1
	1f Material shelf life/out time	1
	1g Material storage and handling	1
2	Composite Materials	1
	2a Identify different structural materials	1
	2b Identify the following with fiber materials	1
	2c Understand the following key characteristics with resins	1
3	Composite Manufacturing	1
	3a Identify the following key components for composite manufacturing	1
	3b Understand the significance of the cure process	1
	3c Understand different manufacturing methods	1
	3d Sandwich composites	1
4	Composite Fabrication (Finish Trim)	1
	4a Apply safety standards, use all appropriate PPE and dispose of waste materials	1
	4b Composite part inspection	1
	4c Trimming composite parts	1
	4d Surface perpetuation for composites (Critical post-cure steps)	1
5	Composite Fabrication (assembly)	1
	5a Use the planning paper/engineering drawing to determine type of makeup of part materials (Kevlar [®] , fiberglass, carbon fiber, or hybrid)	1
	5b Drilling: Key principles to understand	1
	5c Fasteners for mechanically fastening two pieces together and for supporting an existing structure	1
	5d Co-curing/co-bonding with composites	1
6	Composite Fabrication (Paint)	1
	6a Controlling paint thickness on composite	1

PPE = Personal protective equipment

Table A-1. Basic composites curriculum (continued)

Non-Metallic Structures			Level
7	Composite Inspection (Ultrasonic Inspection NDI)		1
	7a	Identify documentation requirements for composite inspection	1
	7b	Define NDI, identify history and evolution of NDI	1
	7c	Identify NDI equipment, NDI testing techniques including tap test, x-ray, ultrasound, thermograph “exotic methods”	1
	7d	Identify differences in in-service inspection vs. production inspection	1
	7e	Identify typical points of inspection during a repair procedure including before repair, damage removal, bagging, cure/set up, repair completion, structural inspection, ready for finish	1
	7f	Identify damage assessment techniques	1
8	Composite Repair (Hot Bond)		1
	8a	Identify materials used in structural repair (prepreg or wet layup)	1
	8b	Understand key steps for prepreg or wet layup repair	1
9	Composite Repair (Electrical Bond)		1
	9a	What is “electrical bonding”	1
	9b	Utilize/read multi-meter	2
	9c	Identify appropriate adhesive–per engineering	1
	9d	Be able to check for electrical bond	2
10	Composite Repair (Bolted-Joint Repair)		1
	10a	What is considered a bolted-joint repair	1
	10b	Advantages of bolted-joint repair	1
	10c	Disadvantages of bolted-joint repair	1
	10d	Preparation for bolted-joint repair	1

NDI = Nondestructive inspection